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# Integration of social spatial data to assess conservation opportunities and priorities

Greg Brown[a,b,*], Clive McAlpine[c], Jonathan Rhodes[c], Daniel Lunney[d,e], Ross Goldingay[f], Kelly Fielding[g], Scott Hetherington[h], Marama Hopkins[h], Clare Manning[i], Matthew Wood[j], Angie Brace[k], Lorraine Vass[l], Linda Swankie[l]

[a] California Polytechnic State University, San Luis Obispo, CA 93401, United States of America
[b] School of Earth and Environmental Sciences, University of Queensland, Brisbane, Australia
[c] School of Earth and Environmental Sciences, University of Queensland, Brisbane 4072, Australia
[d] School of Life and Environmental Sciences, University of Sydney, NSW 2006, Australia
[e] Office of Environment and Heritage, NSW 2220, Australia
[f] School of Environment, Science and Engineering, Southern Cross University, Lismore, Australia
[g] School of Communication and Arts, University of Queensland, Brisbane 4072, Australia
[h] Tweed Shire Council, Murwillumbah, NSW 2484, Australia
[i] Byron Shire Council, Mullumbimby, NSW 2482, Australia
[j] Ballina Shire Council, Ballina, NSW 2478, Australia
[k] Lismore City Council, Lismore, NSW 2480, Australia
[l] Friends of the Koala, Lismore, NSW 2480, Australia

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ABSTRACT

Effective wildlife conservation requires consideration of ecological and social factors, including social acceptability of conservation actions. Using the threatened koala (*Phascolarctos cinereus*) as a case study, we demonstrate a novel, socio-ecological approach for identifying conservation opportunity that spatially connects landscapes with community preferences to prioritize koala recovery strategies at a regional scale. We conceptualize conservation opportunity as the spatial integration of three sustainability criteria—*ecological potential*, *social acceptability*, and *economic feasibility*. The *social acceptability* criterion was assessed using a crowdsourced spatial survey that identified spatial preferences for koalas and land uses that impact koala conservation. As a novel approach, we addressed important research questions regarding the design, collection, and analysis of crowdsourced mapping data for identifying socially acceptable conservation opportunities. Public preferences for koalas were mapped closer to home, in higher suitable koala habitats than expected, were more pronounced in conservation and natural areas on public lands, and were mapped less frequently in modified agricultural landscapes. When the multiple criteria (*ecological*, *social*, and *economic*) were included in the conservation assessment, we found the *social acceptability* criterion exerted the greatest influence on spatial conservation priorities. The systematic assessment of social criteria for conservation using spatial surveys provides information that can be integrated with ecological information to prioritize conservation opportunities. Potential enhancements include expanding survey recruitment efforts and using alternative social data collection methods to achieve greater geographic and socio-demographic representation, and augmenting the economic feasibility assessment with private property values and transaction data from voluntary conservation agreements with private landowners.

## 1. Introduction

Conservation opportunity is a multidimensional concept (Moon et al., 2014) that emerged in recognition of the need to include both social and ecological factors in conservation prioritization and action (Knight and Cowling, 2007; Knight et al., 2010). Conservation opportunity refers to a situation where conditions are favorable for attaining conservation goals resulting from stochastic events or from a systematic process commonly called systematic conservation planning (Margules and Pressey, 2000; Kukkala and Moilanen, 2013) or "informed

* Corresponding author at: California Polytechnic State University, San Luis Obispo, CA 93401, United States of America
*E-mail address:* ggbrown@calpoly.edu (G. Brown).

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opportunism" (Noss et al., 2002). The primary determinants of conservation opportunity include conservation value and vulnerability (Pressey, 1997) and the economic and social dimensions of the feasibility for conservation action (Mills et al., 2013). Conservation opportunities are manifest in a range of planning and policy contexts, such as the creation of parks or reserves, identification of private land for conservation (Knight et al., 2010; Raymond and Brown, 2011; Kamal et al., 2015), retention of biodiversity in existing agricultural landscapes (Norris, 2008), using payments for ecosystem services (Wunder, 2005), human resettlement processes (Harihar et al., 2014), and engaging scientists in conservation action (Schwartz, 2006; Arlettaz et al., 2010).

Although it is widely acknowledged that considering both ecological and social factors is essential to effective nature conservation, there has been contention about the relative importance of ecological versus social factors in the prioritization of conservation efforts (see Knight and Cowling, 2007; Pressey and Bottrill, 2008; Knight and Cowling, 2008). Spatial planning for conservation has traditionally relied on ecological data such as species richness, diversity, or rarity, in combination with area representativeness, complementarity, and adequacy (Pressey, 1994; Margules et al., 1988; Pressey et al., 1993; Bonn and Gaston, 2005; Margules and Pressey, 2000; Myers et al., 2000; Moilanen et al., 2009). However, conservation planning assessments based on ecological information alone will be challenging to implement because they fail to consider social factors (Knight et al., 2008). Recent research has sought to explicitly include social data in spatial prioritization modelling to identify conservation opportunity. For example, social values data have been integrated into spatial optimization models such as Zonation (Moilenan et al., 2005) to identify how values influence priority areas for biodiversity conservation (Whitehead et al., 2014; Karimi et al., 2017). Social data have also been used to identify conservation strategies based on the spatial relationship between social and ecological values (Bryan et al., 2011) and to identify opportunities and constraints in landscape connectivity for conservation (Lechner et al., 2015).

Including social data in spatial prioritization is premised on the importance of social acceptability in evaluating conservation options. Social acceptability is a concept in the social sciences that describes the extent to which a group of people prefer a given situation (Brunson, 1996). Perceptions by local people can provide important insights into the social acceptability of environmental management (Bennett, 2016) and identify conservation policies that are acceptable locally (Engen et al., 2018). Assessing the social acceptability of conservation alternatives can be done using a range of social research methods including survey research (e.g., Kideghesho et al., 2007; Ford et al., 2009), interviews (Loker et al., 1999; Voyer et al., 2015), choice experiments (Horne, 2008), and Q methodology (Gall and Rodwell, 2016). Social acceptability can also be assessed through advisory groups and institutions intended to represent local community interests (Game et al., 2011). But assessing social acceptability is complex because public judgments about acceptability derive from a poorly understood set of factors, including issue context, trust, aesthetics, and personal history (Stankey and Shindler, 2006).

Participatory mapping methods, commonly called public participation geographic information systems (PPGIS), participatory GIS (PGIS), and volunteered geographic information (VGI), have increasingly been used to assess conservation opportunity based on the spatial relationships among ecological values, social values, and public preferences for land/marine management (Lechner et al., 2015). Participatory mapping methods have significant advantages over traditional social assessment methods because: (1) social data collected are spatially-explicit and can identify specific geographic locations where conservation alternatives are supported or opposed, (2) population sampling is typically larger, broader, and potentially more representative than traditional conservation stakeholder processes, (3) spatial data can be readily integrated with spatial ecological data to assess conservation trade-offs, and (4) the mapping process can contribute to increased social capacity.

In this study, we present and evaluate a novel, socio-ecological approach where we connected landscapes with local communities to prioritize investment in koala (*Phascolarctos cinereus*) recovery and monitoring strategies at a regional scale. We argue that spatial conservation opportunity is closely related to social acceptability and can be operationalized through participatory mapping methods. We demonstrate how spatial preferences for wildlife and land use, collected through a crowdsourced internet mapping application, can be integrated with place characteristics to identify locations of conservation priority for wildlife. Our case study example involves conservation of the iconic, but vulnerable koala in the far north coast region of New South Wales (NSW), Australia.

### 1.1. A case study in koala conservation

In human-modified landscapes, native species, such as the koala, compete for space with humans resulting in trade-offs between conservation and development. The koala is an excellent species to evaluate conservation opportunity through participatory mapping because the koala enjoys favorable public attitudes (Woods, 2000; Shumway et al., 2015) and occurs primarily on private land (Lunney et al., 2000). The koala has experienced significant population declines in Queensland, New South Wales and Australian Capital Territory where the species is now listed as "vulnerable" under the Australian *Environment Protection and Biodiversity Conservation Act* (1999). In the geographic location of this case study, the far north coast of NSW, koala populations are experiencing significant pressures from loss of habitat, human-induced mortality (e.g., from cars and dogs), and the spread of infectious diseases (Rhodes et al., 2011; Goldingay and Dobner, 2014; McAlpine et al., 2015; Lunney et al., 2016). In the absence of additional conservation action, koala populations are expected to decline (McAlpine et al., 2015). Recovery options are constrained by a variety of factors including the unwillingness of dog owners to restrain their dogs at night, roadkill, and the unavailability of areas for restoration (Ng et al., 2014). The *National Koala Conservation and Management Strategy* (2009–2014) advocated increased consideration of koala habitat in development planning; greater conservation of high-quality habitat through legislation, covenants or agreements; more active land management to protect koalas; and increased community capacity and partnerships that foster conservation (Natural Resource Management Ministerial Council, 2009).

There are specific proposals to establish large conservation reserves, rather than small reserves, in NSW to protect koala habitat at a landscape level (see Love and Sweeney, 2015; Walker, 2018). One proposal calls for the creation of a large national park in and around Bellingen and Coffs Harbour on the mid north coast of NSW. While this proposal may well make a first-rate national park, it will not assist the conservation of the koala populations on the far north coast (i.e., our study region) because the koala populations of the mid north coast are not connected to the far north coast. The principle of dedicating a large national park in the far north coast as the solution to conserving koalas does not address the problem in this region because koalas are dispersed through a broad matrix of urban development and agricultural land, which is criss-crossed by numerous freeways and arterial roads. What is needed in this region, and potentially in every region, is a range of local and regional koala recovery and conservation actions involving collaborative efforts between local government, NGOs, and landholders, both in conserving koala habitat and managing the follow-on effects of habitat loss, particularly roadkill, dog attacks, and disease. The need for a series of local conservation actions lies at the core of our study, namely to seek socially acceptable conservation actions consistent with an ecologically robust framework.

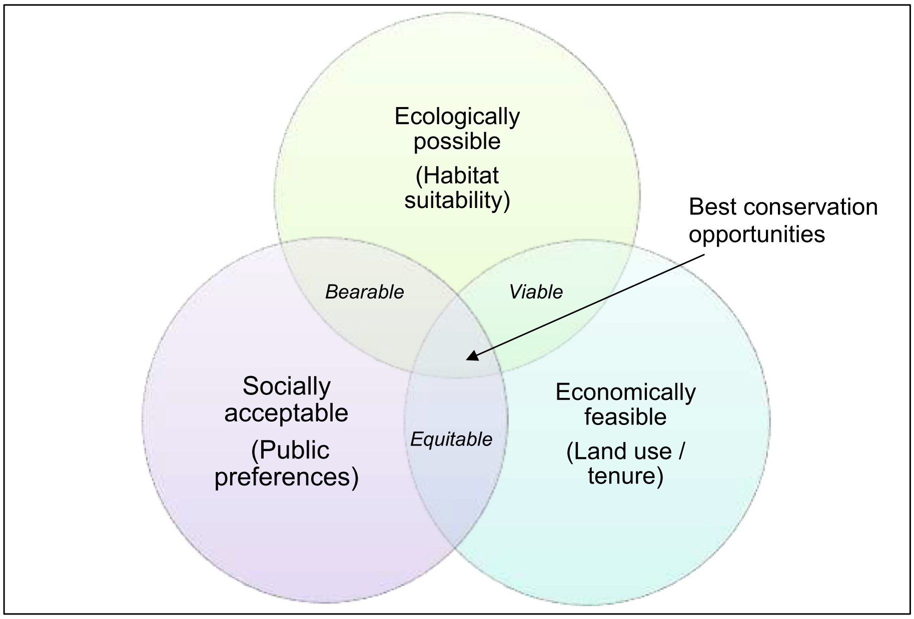


**Fig. 1.** Conservation opportunity identified as geographic locations that meet ecological, social, and economic criteria.

### 1.2. Identifying spatial conservation opportunities

Spatial conservation *opportunity* can be identified by examining the ecological, social, and economic conditions that contribute to its realization. From an ecological perspective, spatial locations that support the biophysical conditions for a species to thrive provide the best opportunities for conservation. From a social perspective, areas that enjoy broad public support for conservation activities (e.g., protective regulations) provide the best conservation opportunities. And from an economic perspective, areas that offer cost-effective solutions provide the best opportunities for conservation. Each perspective is valid and will likely generate a different set of spatial priorities for conservation. Ideally, the best conservation opportunities are identified by the convergence of these three criteria (Fig. 1). Spatial locations that meet these criteria provide a rational basis for ranking and prioritizing local and regional conservation opportunities.

In this study we examined the social acceptability criterion in-depth because scientists and practitioners increasingly recognize that social factors are often the primary determinants of conservation success or failure, leading to a call for the social sciences to become central to conservation science and practice (Mascia et al., 2003; Bennett et al., 2017). However, social acceptability has been rarely assessed spatially for conservation planning. Participatory mapping using spatially-explicit surveys can generate social data to identify locations that are socially acceptable for wildlife conservation. The types of place attributes that have been mapped in past research include landscape values, ecosystem values, land use preferences, activities, and experiences (Brown and Kyttä, 2014). Spatial preferences about different types of land or marine uses (e.g., residential or tourism development) are typically phrased in terms of support or opposition to a prospective land use in the marked location (e.g., Brown et al., 2018a) or an increase (decrease) in the intensity of land use activity (Hausner et al., 2015). Spatial preferences can also measure a desired future condition such as the presence of more koalas in a given geographic location. Underlying these spatial preferences for more koalas is the idea of *wildlife acceptance capacity*, a social psychological construct describing perceptions of a species' impact that is grounded in experience, beliefs and attitudes, aesthetic appeal, type of benefits and costs, perceptions about population trends, and attitudes toward management of the species (Decker and Purdy, 1988; Riley and Decker, 2000). Although acceptance can be framed in relation to negative perceptions involving nuisance factors (e.g., suburban deer browsing in gardens), acceptance can be also driven by positive, affective perceptions of the species. Spatial preferences for koalas are an operational measure of the multiple and complex psychological factors that underlie public judgements about the desirable number and geographic location for koalas in the planning area.

To identify local and regional conservation opportunities, we examined the three spatial criteria—*social*, *ecological*, and *economic*—-separately and then in combination to identify and rank the best opportunities. The spatial variables used to assess social acceptability consist of preferences for: (1) more koalas; (2) different types of land use affecting koala conservation—residential, commercial, or tourism development and new parks/reserves; and (3) regulations of dogs that pose a threat to koalas and road rules that reduce mortality from cars. The spatial variables used to assess economic feasibility consist of: (1) current land use; and (2) land tenure/ownership (private land, public lands consisting of NSW state or Crown lands, Local Government land, and parks/reserves). Crown lands in Australia are public lands held in the right of a State with most managed by the State rather than Commonwealth government. The ecological criterion was koala habitat suitability from a published koala habitat model.

The spatial unit of analysis for examining conservation opportunities is important given that spatial preferences and features of place have different spatial resolutions. The spatial unit of analysis should be meaningful to evaluate the overarching objective, in this case, evaluating and prioritizing areas for koala conservation. A spatial grid approach provides for the integration of disparate data, consequently the size of the grid cell is important. We selected a 1 km grid cell size for analysis given the relatively coarse resolution of mapping preferences that are only accurate within 100 s of meters, the resolution of the koala habitat model (250 m), and the average home range of koalas in the study area—8 to 37 ha depending on method (Goldingay and Dobner, 2014).

### 1.3. Purpose and research questions

As observed by Stratford et al. (2000), there remains a gap in acknowledging the social factors that influence decisions about koala conservation. Previous research using spatially-explicit social data examined the potential influence of social values on general biodiversity conservation allocations (Whitehead et al., 2014; Karimi et al., 2017;

Lechner et al., 2015), not species-specific conservation opportunities. In this study, the public was asked to map their locational preferences for *more* koalas, preferences for land use that affect koala habitat, and preferences for regulations with the potential to reduce koala mortality. These variables are posited to represent the social acceptability of conservation options within the region. The identification of public preferences for *more* koalas is a key variable that is linked to the ecological reality confronting the koala where *more* koalas (or specifically, more places where they occur) are needed to achieve their persistence in the region. The study design, collection, and analysis of the crowdsourced data raise important questions about the process and the quality of the data, and its utility for determining regional priorities for investment in koala conservation. We sought answers to the following research questions:

1) How are spatial preferences for more koalas distributed in the study region and are these preferences related to participant characteristics (e.g., home location and socio-demographic variables such as age, gender, education, and self-reported knowledge of koalas)?
2) What are the spatial relationships between preferences for more koalas and habitat suitability, current land use, and land tenure?
3) How do ecological, social, and economic spatial criteria, separately and in combination, influence the identification and ranking of conservation priorities in the region?

Following analyses to answer these questions, we demonstrate how primary spatial survey data can be integrated with ecological and land use/tenure data from secondary sources to identify conservation opportunities and priorities. Although the case study is specific to the koala, the conservation assessment method can be adapted to other species and geographic contexts.

## 2. Methods

### *2.1. Study area*

The study area was located on the far north coast of New South Wales, Australia, and consisted of four Local Government Areas (LGAs)—Ballina Shire, Byron Shire, City of Lismore, and Tweed Shire. Population estimates (Australian Bureau of Statistics, 2016) for the four LGAs were as follows: Ballina Shire (41,790); Byron Shire (31,556); City of Lismore (43,135); and Tweed Shire (91,371). The study area supports koalas, a species listed as vulnerable under State and Commonwealth laws. The area is also the focus of a range of recovery projects including a recent joint Commonwealth and local government ecosystem restoration project called “Tweed Byron Koala Connections” that sought to secure the future of koala populations by increasing the area, quality and connectivity of habitat. The project resulted in the planting of > 76,000 trees in 120 locations across the two local government areas (Echonetdaily, 2016).

### *2.2. Study design and crowdsourced data collection*

We developed an internet survey in 2017 to assess resident willingness to positively engage in koala conservation and recovery programs. The survey used a custom Google® maps application where participants were directed to drag and drop digital markers representing locations where koalas were observed and to identify spatially-explicit land use and regulatory preferences in the study area. Text-based survey questions were developed and coded using PHP/HTML with responses recorded in a MySQL database. Further details on the specific survey methods may be found in Brown et al. (2018b). Of relevance to this study were markers that requested participants to identify locations where: (1) they would prefer to see more (or fewer) koalas, (2) they had preferences for four types of land use that affect koala habitat (residential, commercial/industrial, tourism, and new national parks/reserves), and (3) they had regulatory preferences for allowing dogs in an area, modifying road rules for koala safety (e.g., reduced speed), and using prescribed fire in koala habitat. The land use preferences and regulatory markers provided options to express preferences either favoring or opposing the land use or regulation. For example, a participant could mark locations in favor of residential development as well as locations where residential development should not occur. The number of markers a participant could map was not limited. The survey also included text-based questions that identified participant characteristics such as home location, age, gender, and formal education, as well as participant's knowledge of koalas, familiarity with the study area, attitudes toward koalas, perceived threats for koala survival, and support for various types of koala conservation efforts.

Survey participants were recruited through five primary sources: (1) local government (LGA) newsletters and websites, (2) conservation and community organizations such as “Friends of the Koala” and “Bangalow Koalas”, (3) Facebook® advertisements, (4) news stories appearing in local media including newspapers and radio, and (5) friend and relative referrals from the above sources. The survey and data collection was open from December 2017 through March 2018 (approximately 4 months). There was a modest prize draw to encourage participation.

### *2.3. Spatial data (place variables) used in analysis*

Multiple spatial data sets were used in the analysis of mapping preference data. The map for suitability of koala habitat was based on a predictive koala habitat model that assessed the relationship between historical koala records and 14 environmental variables that included vegetation productivity, soils, forest type, topography, climate and frequency of wildfire (Law et al., 2017). The habitat model has a spatial resolution of 250 m and ranks each grid cell on a scale from 1 to 9, from low to high habitat suitability.

Land use data were derived from national catchment-scale land use data for Australia (CLUM) updated as of September 2017 (Australian Government, 2017). The raster data were compiled at a spatial resolution of 50 × 50 m that combined land tenure with other types of land use information. The primary classes of land use in the data set were: (1) conservation and natural environments, (2) production from relatively natural environments, (3) production from dryland agriculture and plantations, (4) production from irrigated agriculture and plantations, (5) intensive uses generally associated with residential settlement, commercial, or industrial uses, and (6) water features.

Land tenure and property data were obtained from the New South Wales Spatial Digital Cadastral Database (DCDB) consisting of 46 tables or layers, representing different aspects of land and property boundaries (NSW Government, 2018). These data include boundaries for government and private land, state forests, national parks and wildlife reserves, water, and road corridors. Of special relevance to conservation assessment is land tenure data that are classified into public lands (NSW State or Crown lands), Local Government, and Freehold (i.e., private land) categories.

### *2.4. Analyses*

#### *2.4.1. Participant characteristics (geographic and demographic) and mapping behavior*

We assessed the geographic representativeness of participants by comparing the proportion of participants within each local government area to the expected distribution based on census data and by plotting home locations in the study region area to compare with population density based on the 2016 Australian census. We used descriptive statistics to analyse participant characteristics (age, gender, education) to compare with census data.

Mapping behavior was analysed by the type and number of preference markers mapped by participants and the quantitative relationship between marker counts and other participant variables including age, gender, education level, length of residence, knowledge of the study area, knowledge of koalas, and distance from home. Specifically, we analysed whether participant subgroups such as men and women or longer-term residents mapped more or fewer preferences for having more koalas in the study area.

#### 2.4.2. Spatial distribution of mapped preferences in the planning area

The spatial data from the survey were prepared and analysed using ArcGIS® v10.4. Preference data, collected as point features, were clipped to the planning area boundary. A spatial fishnet grid (1 × 1 km) was generated and overlaid on the study area resulting in 3663 grid cells for analysis. Preference point counts were tabulated in each grid cell and a simple point density map was generated for preferences for wanting more koalas.

#### 2.4.3. Relationship of preferences to koala habitat suitability

The relationship between preferences for more koalas and koala habitat suitability (Law et al., 2017) was analysed by creating a 1000 m circular buffer around each preference point (1854 points). Each grid cell (250 m) in the habitat model was assigned a suitability score scaled from 1 (lowest suitability) to 9 (highest suitability). The buffered preference points were intersected with the koala habitat suitability map and for each preference location, a mean habitat suitability score was calculated and assigned to the preference point. The spatial distribution of preferences by mean habitat suitability score was plotted and compared to the general distribution of habitat quality across the study area. The two distributions were tested statistically for differences using a *t*-test (mean scores) and for differences in the cumulative distributions using Kolmogorov-Smirnov Z test.

#### 2.4.4. Relationship of preferences to land use

The relationship between preferences for more koalas and land use was examined by intersecting the preference points with a land use map layer (Australian Government, 2017). The land use layer was classified into six primary land use categories (see above) with a spatial resolution of 50 × 50 m. The areas of primary land use located within a 1000 m buffer around each preference point were tabulated and the primary land use category with the largest area (i.e., majority land use) was assigned to the preference point. The areal proportion of primary land uses across the study area was tabulated for comparison to land use associated with the preferences. The proportion of preferences by land use category (actual) was compared to the general distribution of land uses across the study area (expected proportion).

#### 2.4.5. Relationship of preferences to land tenure

Land tenure data were accessed from the New South Wales Spatial Digital Cadastral Database. Approximately 90,000 parcels (lots) of land were classified and analysed based on the following land tenure categories: Freehold, NSW Government, Crown, Local Government, and National Parks/Nature Reserves. The National Parks/Nature Reserves category is a subset of NSW Government land with a specified conservation purpose. Preferences for more koalas were intersected with the 1 km fishnet grid where the majority land tenure category was calculated based on tabulated parcel area by tenure in the cell. The proportion of preferences identified by majority tenure category (actual) were compared to the general distribution of land tenure categories across the study area (expected).

#### 2.4.6. Multi-criteria identification and ranking of conservation opportunity

To identify and rank conservation opportunities, we used multiple criteria representing the concepts of social acceptability, ecological potential, and economic feasibility that were operationalized using data from primary and secondary sources (Table 1). Social acceptability was measured by the number of mapped preferences for koalas as well as land use and regulatory preferences. Ecological potential was based on a koala habitat suitability model (Law et al., 2017), and economic feasibility was based on two variables—current land use and land tenure. A quantitative index for each criterion was calculated and standardized for each 1 km grid cell in the study area. The top 20% of cell values for each criterion were identified and mapped to show priority conservation areas based on each criterion. This 20% threshold was selected merely for purposes of illustration while recognizing that a range of prioritization thresholds could be used in the analysis. The values of the three criteria were then summed in each grid cell (equal weighting) to generate an integrated measure of conservation opportunity, with the largest values representing the best conservation opportunities in the region.

Because koalas are found primarily on private land, we refined the analysis to focus on conservation opportunities associated with private land in the region. We analysed conservation opportunities using only the criteria of habitat quality and social acceptability (preferences for more koalas) without the economic feasibility criteria. The top 20% of cell values were identified that met these criteria, and this spatial subset was further refined by identifying cells with > 25% private land. These cell locations were then analysed by majority land use as an indicator of the potential challenges in managing these locations for koala conservation. For example, locations that are proximate to production agriculture or intensive land uses such as residential development may require significant land use change and/or regulatory interventions to achieve koala conservation objectives.

## 3. Results

### 3.1. Participant characteristics

There were 436 participants that mapped one or more preference locations in the study area and 379 participants that completed the post-mapping survey questions. Participants were 70% female, averaged 53 years of age, and had a high level of formal education, with 66% having a bachelor's degree or higher. Compared to Australia Bureau of Statistics population statistics, study participants were older, contained proportionately more females, and had a significantly higher level of formal education (Table 2). The sampling bias on age and formal education was consistent with many participatory mapping studies, but inconsistent in that participation is most often skewed toward greater male participation (Brown and Kyttä, 2014).

Participants were asked to self-rate their knowledge of koalas as well as their familiarity with places in the study area. About 58% of participants rated their familiarity with the study area as “excellent” or “good” while only 2% rated their familiarity as “poor”. With respect to knowledge of koalas, about 16% rated their knowledge as “very high” or “high” while about half of participants rated their knowledge as “moderate”. In terms of geographic representation, 99% of participants were residents in the study area with an average 20 year residency. Participants were proportionately over-represented in the Local Government Areas (LGAs) of Byron and Lismore and under-represented in Ballina and Tweed Shires. For example, Lismore has about 21% of the study area population but accounted for 35% of the participants while Ballina has about 20% of the study area population but accounted for only 8% of participants. The geographic distribution of participants based on home location was consistent with population density in the study area with higher concentrations of participants clustered near the population centres of Lismore, Tweeds Head, Pottsville, and Murwillumbah.

The largest number of preferences was to have more koalas (1854 markers, 273 individuals). Only 9 individuals (33 markers) mapped preferences for fewer koalas. Participants mapped significantly more preferences in opposition to residential (526 markers, 105 individuals), commercial (185 markers, 67 individuals), and tourism development (205 markers, 49 individuals) than preferences in favor of these types of development. Preferences for new parks/reserves (242 markers, 72

**Table 1**
Multi-criteria scoring for ranking conservation opportunities in the study region.

| Criteria | Spatial variables | Source | Grid cell calculation (standardized) | Interpretation |
|---|---|---|---|---|
| Social acceptability | Number of koala preferences (more or less)<br>Number of unique individuals<br>Development preferences (oppose)<br>Residential, commercial, tourism<br>Development preferences (favor)<br>Residential, commercial, tourism<br>Regulatory preferences (favor)<br>Dogs, driving rules, prescribed fire<br>Regulatory preferences (oppose)<br>Dogs, driving rules, prescribed fire | Spatial social survey | [number koala preferences (more) + number of individuals + development preferences (oppose) + regulatory preferences (favor)] – [number koala preferences (less) + development preferences (favor) + regulatory preferences (oppose)] | Larger scores indicate greater social acceptability based on public preferences for land uses and regulations favorable to koalas |
| Ecological potential | Habitat suitability. Scale 1 (lowest) to 9 (highest) | Habitat suitability model (Law et al., 2017) | Mean habitat suitability for cells with at least 20% habitat suitability data | Larger means indicate higher quality habitat |
| Economic feasibility | Land tenure<br>3 = NSW State or Crown<br>2 = Local government<br>1 = Freehold<br>Current land use<br>4 = Conservation<br>3 = Production in natural environment<br>2 = Production in dryland or irrigated agriculture<br>1 = Intensive uses | New South Wales Spatial Digital Cadastral Database (DCDB)<br><br><br><br>Catchment scale land use data (Australian Government, 2017) | Land tenure + current land use | Larger scores indicate greater feasibility to implement conservation measures. Private land requires landowner consent. More heavily modified landscapes (i.e., urban, agriculture) require greater expense to convert, restore, or manage for koala habitat. |

**Table 2**
Participant profile based on survey responses in the study area. Participants only marking home location and no other markers ($n$ = 54) were excluded from analysis. Selected census demographics from the 2016 ABS Census are provided for comparison. Not all percentages total 100% due to rounding.

| Mapping behavior | | | | |
|---|---|---|---|---|
| Number of participants (mapped one or more locations) | 436 | | | |
| Number completing post-mapping text survey | 379 | | | |
| Number of locations mapped | 6328 | | | |
| Range of preference markers mapped[a] | 1–75 | | | |
| Preference marker counts (number of individuals) | | | | |
| Preferences for koalas | More | 1854 (273) | Less | 33 (9) |
| Residential development | Favor | 138 (47) | Oppose | 526 (105) |
| Commercial/industrial development | Favor | 19 (16) | Oppose | 185 (67) |
| Tourism development | Favor | 31 (20) | Oppose | 205 (49) |
| New parks/reserves/conservation areas | Favor | 242 (74) | Oppose | 5 (5) |
| Dogs allowed | Allowed | 57 (26) | Not allowed | 162 (56) |
| New driving rules for koala safety | New rules | 248 (75) | No new rules | 13 (8) |
| Prescribed fire for koala habitat | Prescribed fire | 35 (13) | No prescribed fire | 53 (17) |
| Knowledge of study area | | | | |
| Excellent | 14% | | | |
| Good | 44% | | | |
| Average | 33% | | | |
| Below average | 7% | | | |
| Poor | 2% | | | |
| Knowledge of koalas | | | | |
| Very high knowledge | 4% | | | |
| High knowledge | 13% | | | |
| Moderate knowledge | 48% | | | |
| A little knowledge | 33% | | | |
| No knowledge | 3% | | | |
| Resident of study area | | | | |
| Yes | 99% | | | |
| No | 1% | | | |
| Years lived in study area (mean, median) | 20, 18.5 | | | |
| Participant distribution by Local Government Area (percent) | | | | |
| Ballina (percent of study area population = 20%) | 8% | | | |
| Byron (percent of study area population = 15%) | 24% | | | |
| Lismore (percent of study area population = 21%) | 35% | | | |
| Tweed (percent of study area population = 44%) | 33% | | | |
| Demographics | | | | |
| Gender (ABS for NSW 2016: Male 49.3%) | | | | |
| Female (%) | 70 | | | |
| Male (%) | 30 | | | |
| Age in years (mean/median) (ABS for NSW 2016: mean 48, median 47)[b] | 52/53 | | | |
| Education (%) (ABS for NSW 2016: 23.4% Bachelors/postgraduate) | | | | |
| Less than Bachelors | 34% | | | |
| Bachelor's degree/postgraduate | 66% | | | |

[a] Preferences for seeing more koalas limited to maximum of 75 markers.
[b] Estimates from 2016 grouped census data for individuals aged 20 or older.

individuals) greatly exceeded preferences in opposition (5 markers, 5 individuals). Regulatory preferences for not allowing dogs in some areas (162 markers, 56 individuals) were greater than preferences to allow dogs (57 markers, 26 individuals), while preferences for new road rules for koala safety (248 markers, 75 individuals) far exceeded preferences for no new road rules (13 markers, 8 individuals). Preferences for prescribed fire to enhance habitat were more evenly divided, with preferences for no prescribed fire (53 markers, 17 individuals) exceeding preferences favoring prescribed fire (35 markers, 13 individuals). Overall, the large number of mapped preferences in favor of more koalas in the region were consistent with greater preferences in opposition to development that would reduce koala habitat. Regulatory preferences to reduce koala mortality from dogs and cars were also strongly favored.

The relationships between participant characteristics and mapping preferences for more koalas were examined in greater depth. Older ($t = -2.15, p < 0.05$), female ($\chi^2 = 4.38$, $p < 0.05$), and individuals with greater self-rated knowledge of koalas ($t = -2.6$, $p < 0.05$) were statistically more likely to map preferences for more koalas. The participant's level of formal education ($X^2 = 0.90$, $p > 0.05$), length of residence ($t = -0.53$, $p > 0.05$), and self-rated knowledge of the study area ($X^2 = 0.37$, $p > 0.05$) were unrelated to the propensity to map preferences for more koalas. The distance between a participant's residence and mapped preferences showed that participants preferred koalas closer to home with about a third of total mapped preferences located within 1000 m of home and 50% within 3000 m.

### 3.2. Spatial distribution of mapped preferences for more koalas in the planning area

The distribution of preferences for more koalas deviated significantly from complete spatial randomness (CSR) with a tendency toward clustering (nearest neighbor ratio = 0.57, $z = -35.3$, $p < 0.001$) (Fig. 2a). The greatest intensities of preferences were concentrated on the north coast near Pottsville, south of Lismore, and near the community of Bangalow, and several locations in the rural, western reaches of the study area (Fig. 2b). Four high preference areas, identified by circles, were strongly influenced by 1–2 individual participants who placed a relatively large number of preference markers (Fig. 2c).

### 3.3. Relationship of preferences to habitat suitability

The distribution of preferences for more koalas were generally mapped in areas identified as suitable *koala habitat* (Fig. 3a). Mean habitat quality for all preferences was 5.5 (scale 1 to 9) with only one

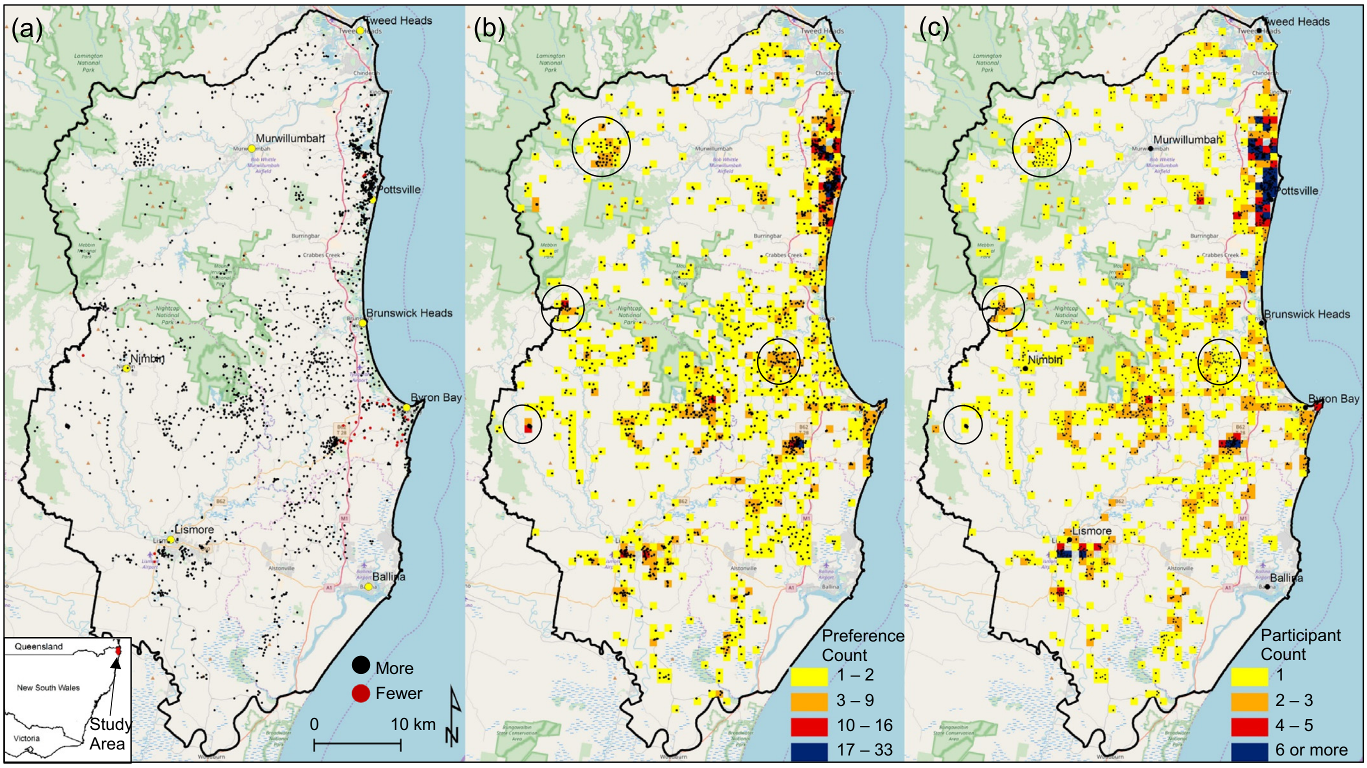


**Fig. 2.** Distribution of (a) mapped preferences for more koalas (1854 black points) with preferences for fewer koalas (33 red points); (b) preferences for more koalas within 1000 m grid cells, and (c) number of unique individual mapping preferences for more koalas with circles indicating areas influenced by a single individual. The green areas are State-owned land, i.e. National Parks or Nature Reserves. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

preference mapped in a location with low habitat quality (< 3). Participants mapped preferences in significantly greater habitat suitability areas (*t*-test, $p < 0.001$) than found across the study region, with the cumulative distribution of the habitat quality scores for preferences (Fig. 3b) also greater (Kolmogorov-Smirnov Z test, $p < 0.001$).

### 3.4. Relationship of preferences to land use

The preferences for more koalas were disproportionately more concentrated in the land use category of *conservation and natural environments* (32% of preferences, 22% of study area) and disproportionately less so in the category of production from dryland agriculture and plantations (30% of preferences, 39% of study area). Preferences in the other land use categories were roughly proportional to the area of land use within the study area. For example, *production from relatively natural environments* comprised 22% of preference markers and 22% of the land area while *intensive uses* (e.g., urban development) comprised about 12% of both preferences and land area.

### 3.5. Relationship of preferences to land tenure

The preferences for more koalas were disproportionately more concentrated in *NSW Government* (10% of preferences, but < 1% of study area) and *Crown* land (5% of preferences, 2% of study area), and disproportionately less so in the category of *National Parks/Nature Reserves* (3% of preferences, 10% of study area). Freehold land is the majority land tenure category with about 97% of the total parcels (e.g., parcels with homes). The number of mapped preferences (~80%) in freehold land was roughly proportional to the area of freehold hand in the study area (81%), as were mapped preferences in local government land (< 1% of preferences, < 1% of study area).

### 3.6. Conservation opportunity prioritization

Conservation opportunity priority maps were generated using the top 20% of standardized scores for the ecological, social, and economic criteria (Fig. 4). These standardized scores were summed and equally weighted. The best conservation opportunities derived from ecological potential were located in coastal areas (Fig. 4a). Opportunities based on social acceptability were widely dispersed between coastal and inland areas (Fig. 4b), and opportunities based on feasibility were primarily located inland in existing national parks and nature reserves (Fig. 4c). These visual differences in geographic locations were evidenced by modest spatial overlap among the three criteria. The amount of spatial overlap between top ecological locations and top social acceptability locations was 32% while the spatial overlap between ecological and feasibility criteria was 34%. The amount of spatial overlap between social acceptability and feasibility was lowest at 25%. The relative influence of each criterion on the combined priorities map (Fig. 4d) was assessed by spatial overlap as follows: ecological (35%), social (65%), and economic (62%). Overall, the three criteria contributed different information to the identification of spatial conservation priorities with social and economic criteria exerting a stronger influence on the combined spatial outcome when the criteria were weighted equally.

To examine conservation opportunities associated with private land in greater depth, we simplified the selection criteria to ecological potential (habitat quality) and social acceptability (preferences for more koalas). The top 20% of these grid cells based on these two criteria were further filtered by those cells containing 25% or more private land (Fig. 5). These cells were then analysed by majority land use with a finding that about 60% of these lands were currently in production agriculture (cropping and grazing) and 14% in intensive land uses such as residential development. These results indicate that ecologically sound and socially acceptable conservation opportunities for koalas

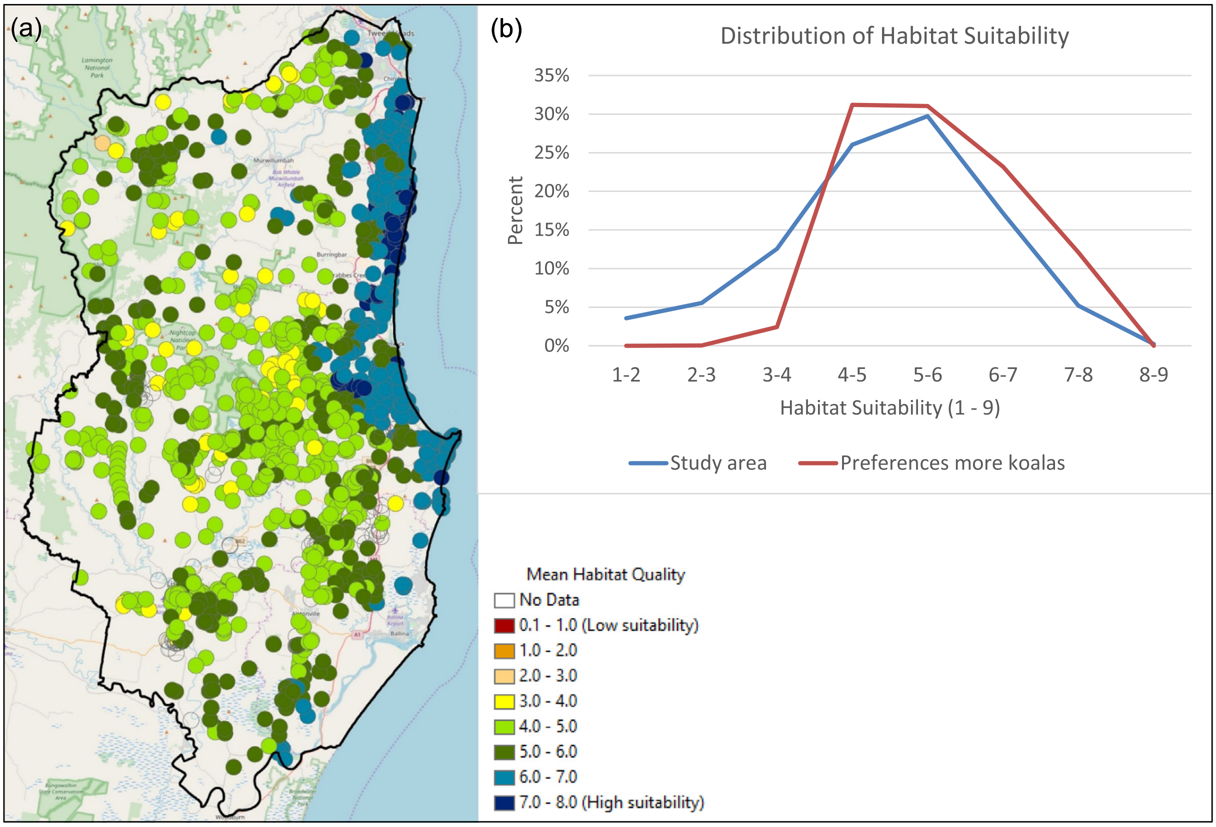


**Fig. 3.** (a) Spatial distribution of preferences for more koalas symbolized by mean habitat suitability within 1000 m of preference points, and (b) frequency distribution of preferences compared to overall distribution of habitat suitability in the study area. Differences in frequency distributions are significant (Kolmogorov-Smirnov Z test, $p < 0.001$) with higher mean habitat quality scores for mapped preferences (t-test, $p < 0.001$).

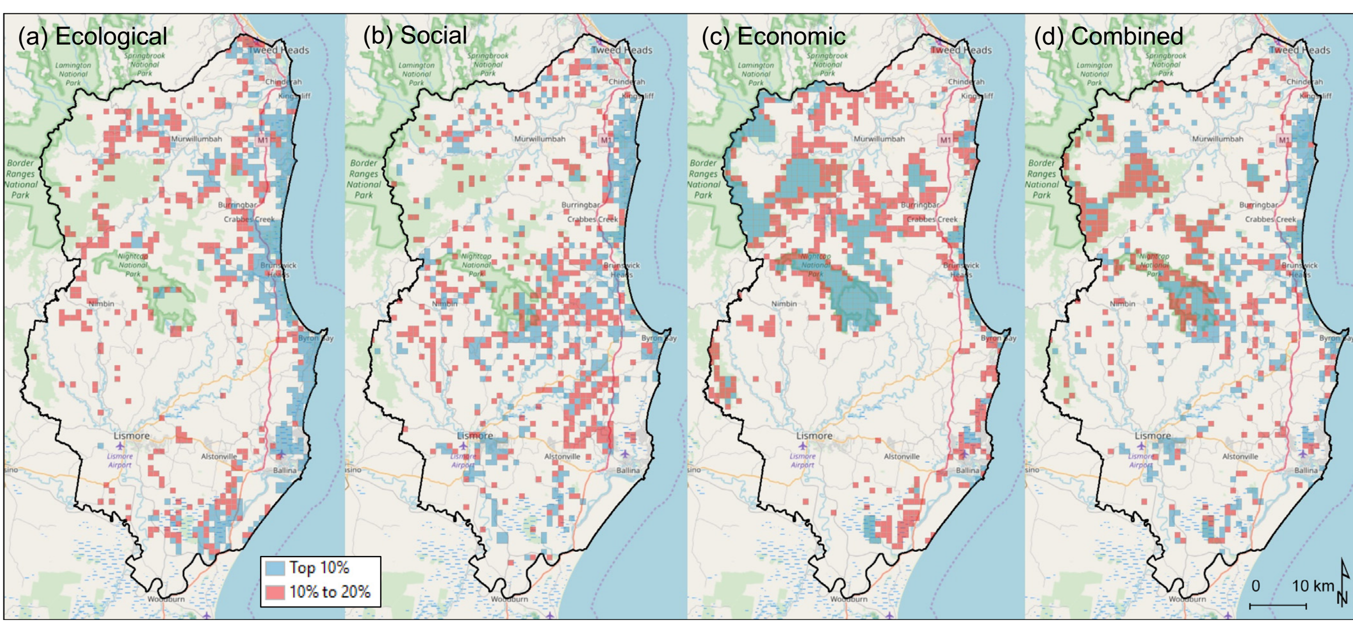


**Fig. 4.** Top 20% of koala conservation opportunities (blue = highest 10%, red = 10 to 20%) identified by: (a) ecological potential (habitat suitability), (b) social acceptability (mapped preferences), (c) economic feasibility (land use + tenure), and (d) the three criteria combined (equal weight). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

disproportionately involve private lands and current land uses that prioritize human use and benefits.

## 4. Discussion

Multiple criteria can be rationally integrated to prioritize conservation resources (Wilson et al., 2009), but a key issue is the selection and weighting of criteria and, in particular, the role of social data. In

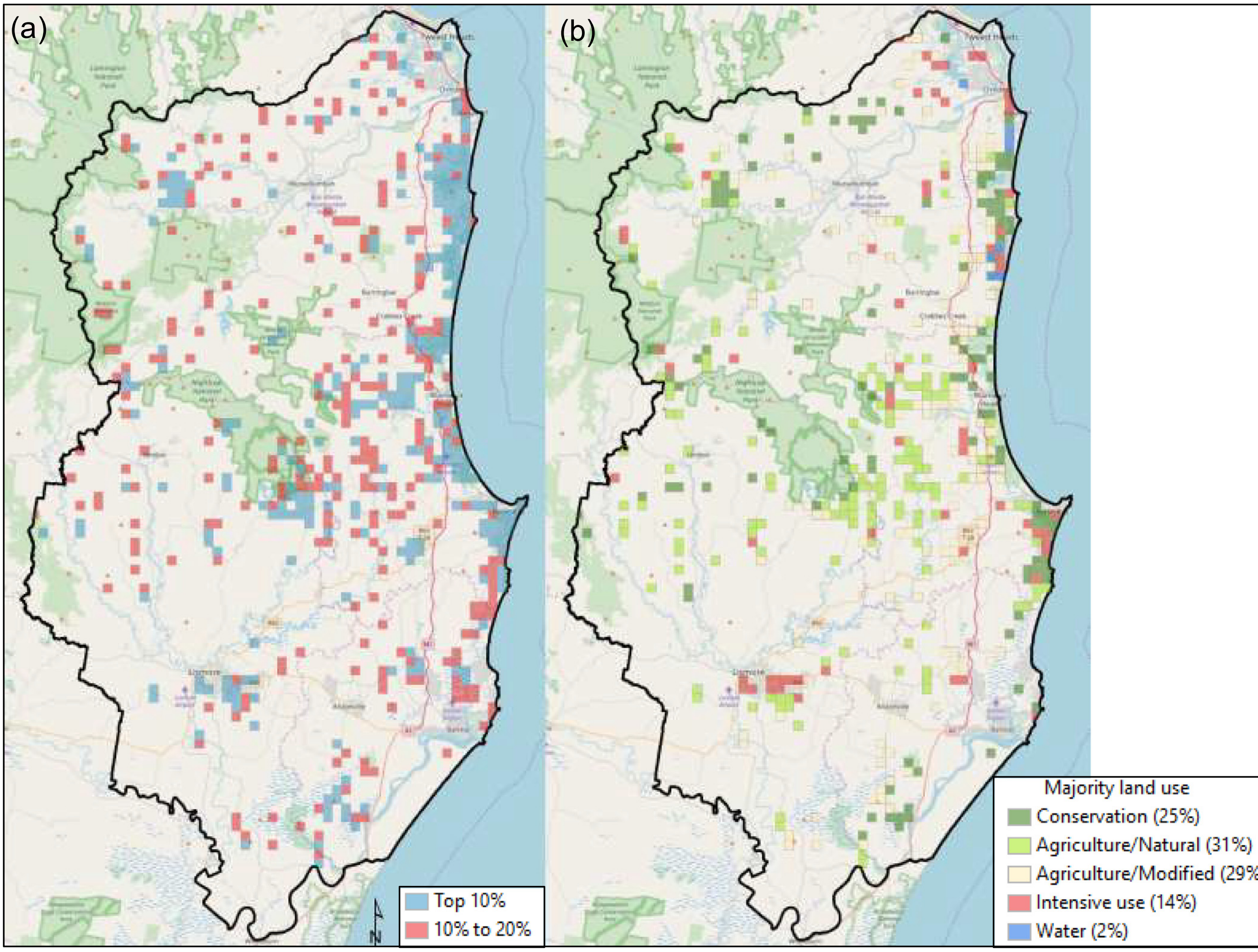


**Fig. 5.** The top 20% of koala conservation opportunities (blue = highest 10%, red = 10 to 20%) identified by: (a) ecological potential (habitat suitability) and social acceptability (preferences for more koalas) with equal weighting, and (b) filtered by locations with 25% or more private land and identified by majority land use. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

this study, we demonstrated how multiple criteria (*ecological*, *social*, and *economic*) can be applied to identify conservation opportunities and priorities for koala conservation. Given the universality of the criteria, the findings from this study have much to offer in the conservation of other species. The social acceptability criterion, traditionally absent in conservation assessments and spatial planning, was operationalized through a regional, crowdsourced spatial survey. Although the method has limitations including participant demographic bias and geographic under-representation in rural areas, the results show that the lay public can produce important and valid spatial information for wildlife conservation assessment. Preferences for koala conservation were significantly related to the ecological criteria (habitat suitability) identifying informed rather than naïve public judgments about viable locations for koala recovery. Further, public preferences were related to the economic criterion as evidenced through disproportionate participant identification of locations that are more feasible for koala conservation efforts such as public lands and forested landscapes. These findings are reinforce previous research showing that lay citizens can effectively contribute to koala conservation by accurately recording koala locations using spatial survey methods (Brown et al., 2018b).

The strength of the multi-criteria method lies in its capacity to identify trade-offs in conservation opportunities, especially in locations on, or near, private lands that typically require significant investment of public resources. Within the study area, agriculture is the dominant land use (~60%) with spatial variation in the type, size, and intensity of farming operations. From research findings elsewhere in Australia, conservation opportunities on these lands are likely to come from smaller hobby farmers who appear *highly engaged* with conservation activities, such as maintaining or restoring native vegetation (Raymond and Brown, 2011). However, larger farms, especially those with large patches of high quality koala habitat, offer greater potential for large-scale conservation in the study region. The next logical step would be to assess private landowner attitudes and willingness to engage in conservation actions for the highest priority areas identified in this analysis, i.e., parcels of private land located within the grid cells identified in Figs. 4d or 5b.

The assessment of conservation value on private land is done at the parcel level and may be preceded by the selection of a general area for conservation program action. This is the current approach taken in NSW under the *Biodiversity Conservation Act 2016* and the *Local Land Services Amendment Act 2016* which established the Biodiversity Conservation Trust (BCT), a non-profit organization whose purpose is to encourage landholders to enter into co-operative arrangements for the management and protection of the natural environment, to seek biodiversity offsets to compensate for the loss of biodiversity, to provide mechanisms for achieving biodiversity conservation, and to promote public knowledge, appreciation, understanding, and the importance of conserving biodiversity (Biodiversity Conservation Trust, n.d.). The principal program of BCT is its Conservation Management Program which provides three mechanisms for private land conservation: 1) tenders from landowners to voluntarily enter conservation agreements in perpetuity or 15 years in exchange for annual payments, 2) fixed rate offers for landowners with important conservation values who receive ongoing payments for developing and implementing a management plan, and 3) a revolving fund to purchase properties in the real estate market that possess high biodiversity conservation values. Conservation value assessment by the BCT operates at two spatial scales, the optional demarcation of a general area for program implementation (i.e., "eligible areas") and the specific site or property assessment.

The conservation assessment method described herein can augment BCT conservation programs by providing intermediate spatial scale analysis (e.g., 1 km resolution) for prioritizing conservation opportunities. Areas can be first ranked by location (grid cell) using multiple criteria, then assessed according to BCT site selection criterion consisting of biodiversity conservation value for money invested. While BCT site assessment methods explicitly consider habitat quality and economic feasibility through tender, fixed offer, or purchase price (the "viable" solution space in Fig. 1), they do not account for the social acceptability of the general location which has the potential to amplify or diminish the conservation investment. For example, the protection or restoration of koala habitat on private land is essential for koala conservation, but should be combined with public acceptance of measures that reduce koala mortality from other significant sources such as cars and dogs. In locations where private land conservation opportunities based on habitat and investment criteria appear comparable, the social acceptability of additional koala conservation measures can be used to prioritize opportunities.

Spatial conservation prioritization methods to guide conservation investment are more likely to be adopted when accompanied by strong collaboration between academics and practitioners (Sinclair et al., 2018). In this case study, there was strong collaboration between the academics and the four local governments in the planning area through all phases of the project, from proposal inception to spatial survey design and implementation, to analysis of the results for identifying conservation opportunities. The final phase of the project—translating spatial priorities into conservation action—is the most challenging as this phase can be socially and politically contentious, in addition to requiring commitment of public resources. But the fact that the social acceptability criterion includes primary data from the region that reflect "bottom-up" community preferences should provide a degree of political leverage for conservation policy implementation.

The assessment method described herein could be improved in several ways: (1) survey recruitment efforts could be broadened to include household sampling to achieve greater geographic and socio-demographic representation. This is especially important for rural areas with low population density. Given the traditional reluctance of rural landowners to participate in survey research, this may require the use of alternative social data collection methods such as face-to-face interviews; (2) the ecological data, based on habitat modelling, would benefit from validation using field studies in sampling locations identified as having both high quality habitat and social acceptability; and (3) the addition of estimated land values for the assessment of economic feasibility. There are significant differences in land values between coastal and hinterland properties in the region that were treated homogeneously in our opportunity assessment. Although private land conservation would not necessarily involve purchase by government or non-profit organizations, land values could be used to estimate the cost of establishing voluntary conservation agreements with private landowners. Over time, transaction data from conservation agreements initiated by the BCT could be used to inform the feasibility criterion.

## 5. Conclusion

The conservation assessment methods described in this paper used a specific case study of koalas in Australia. However, these methods can be applied to other species and geographic locations. Regardless of the wildlife species and location, conservation opportunity analysis will involve an assessment of habitat quality and some type of feasibility analysis, often expressed in economic cost or a willingness of landholders to engage in conservation practices. The social acceptability criterion is an important yet traditionally missing criterion in conservation opportunity assessments. There are some considerations when applying this assessment framework to other geographic contexts. Ideally, the species selected should have strong public recognition to measure social spatial preferences. Although useful to enhance public interest and participation, public attitudes toward the species need not be highly positive, as in the case of the koala. For example, one could envision application of the method to wolves in North America or Europe that are charismatic, but do not enjoy universally positive public attitudes. Flying-foxes *Pteropus* in our study of the north coast of NSW would be also a good test, given the sharply divided public attitudes to these large, fruit-eating bats. Assessment of conservation opportunities using the social acceptability criterion for lesser known and less charismatic species would be more challenging. In this situation, conservation opportunity analysis could be applied to more widely recognized umbrella or keystone species that could serve as a conservation proxy for the lesser known species. With respect to participatory mapping methods to measure spatial preferences, we do not see significant barriers based on geographic context or technology. Participatory mapping methods can utilize a wide range of high and low technology methods in both developed and developing countries and do not appear to be a limiting factor in implementation. As a practical matter in participatory mapping, it is important to handle participant outliers who may map significantly more data than other participants (called "super-mappers") by limiting the number of their markers used in specific spatial analyses. For example, social suitability scores by grid cell can be inflated by a single individual mapping a large number of preferences. The most significant barrier to the methods described herein is the required investment in social research to assess the social acceptability criterion. To make this investment more attractive, researchers and practitioners should consider combining the social research on conservation opportunity with a species citizen science component to increase public interest in the project, as was done in this study.

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